REMARKS

Contrary to the examiner's assertion, U.S. Patent No. 5,451,772 to Narendran does not disclose: "The use of different reflectivities of adjacent reflective structures (see, Col. 4, lines 43-51) to more clearly differentiate discrete responses from the reflective structures".

What Narendran discloses is: "In order to differentiate the discrete responses from the cavities even more, the partially reflective surfaces defining one cavity, may be coated such that they (are) more reflective than the surfaces of the other cavity". It is evident to one skilled in the art that what Narendran teaches is the use of etalons with different "finesses". The reflectivity of the *two ends* of an etalon define a property called the "finesse" of the etalon (F). This defines the reflection characteristic of the etalon with respect to wavelength, or as is equivalent in this case, with respect to extension of the etalon cavity. For the Examiner's benefit, this is described further in the enclosed excerpt of page 367 from the textbook "*OPTICS*" by Hecht.

The examiner goes on to say that: "Therefore it would have been obvious to one of ordinary skill in the art to modify the sensing system of Kersey by varying the reflectivities of each adjacent reflective structure in order to more effectively differentiate between responses from each respective reflective structure".

Varying the finesse requires two reflectivities – one at each end of each of Narendran's reflecting structures (etalons) – as opposed to the present invention in which the reflectivity is a property of the exposure pattern that is used to create the Bragg grating (effectively selective UV damage by an interference pattern). Although, as is evident from Hecht, the finesse does affect the reflectivity, the relationship is not directly linear (it only approximates to linearity as F approaches zero, i.e., small F).

Once established that Narendran teaches modification of the finesse, rather than direct teaching of modification of the reflectivity of the fiber Bragg gratings, the question becomes whether the teaching of finesse modification can be applied to Kersey by one of ordinary skill? Since fiber Bragg grating reflectivity peaks do not possess the property of finesse, it would surely not be possible for one of ordinary skill to apply the teaching of Narendran to U.S. Patent No. 5,748,312 to Kersey.

Fig. 9.46 of Hecht illustrates the response characteristic of an etalon, which is an Airy function: $I_r/I_i = F\sin^2(d/2) / (1+F\sin^2(d/2))$. However, for mathematically small values of F, this approximates to ˜ $F\sin^2(d/2)$. Further from the equality $\sin^2 x = ½ (1-\cos 2x)$ it is evident that for small F, the Airy response approximates to a sinusoidal response (namely, a "raised cosine" response).

Narendran only teaches, and is limited to, the use of low reflectivity structures, in contrast to the present invention which can use peak reflectivities in the range $0 < r < 1$. This limitation is evident from several features of his patent:

Narendran's figures (e.g., Figs. 10-11) teach that the etalons have a sinusoidal shape. From comparison with Fig. 9.46 of Hecht it is evident that this can only be the case for relatively low values of finesse, which would correspond with reflectivities that are substantially less than unity.

This is further supported by Narendran's Fig. 9, which is effectively a Fourier transform of Fig. 8. This only shows a single peak for each etalon, which would correspond with low values of finesse (higher finesse values would have harmonic components – i.e., each etalon would have several peaks - which would further complicate their identification and limit the range of principal reflectivities available).

Further, Narendran's proposed device comprises several etalons in series. Since each device will generally reflect a proportion of the light, then this would only be possible with low reflectivity etalons, i.e., low finesse values, or would provide a significant limitation to the number of etalons that can be used in single fiber, which would have to be counter-balanced with the strength of signal required for detection. In contrast, the use of individual narrow peaks, as per the present invention, does not suffer this limitation. (Similarly Kersey's device has to compromise between the number of FBGs and their operating bandwidth, to avoid crossing of FBG peaks, in wavelength.)

Lastly, high F values are not suited to strain measurement, since they are not sensitive to change over most of their range, for which the reflection is close to unity.

Kersey relates to polychromatic systems which us a tunable laser and broadband detector.

In contrast, Narendran is a monochromatic system which uses a single wavelength laser and narrow bandwidth detector.

With the present invention, a single measurement (wavelength scan by laser) can unambiguously determine the strain at all of the sensors for a large range of operating strains, if neighboring sensors have different characteristic responses, thereby providing a device that is suitable for 'one-shot' measurements without knowledge of its operating history. Going even narrower – it would be possible to provide each sensor with a unique reflection characteristic, thereby enabling all sensors to 'cross' (limited only by the laser operating range).

The number of sensors for Kersey's device is limited by the operational bandwidth that each sensor requires – the reflection peak of each sensor can shift by approximately +/- half the separation of the wavelength peaks, before there is a risk of overlapping of adjacent peaks. Since the operational bandwidth of the tunable laser is limited, this operational bandwidth of each sensor

restricts the number of sensors that can be used in series. (Once Kersey's peaks have overlapped, they can no longer be distinguished.) Consequently, Kersey's device cannot be used for one-shot measurements over a large range of strains.

The etalons of Narendran have a repeating reflection characteristic (see Hecht's figures), and so even just a single etalon has a limited bandwidth when used for a monochromatic one-shot measurement (in fact limited to half of the free spectral range, FSR, due to the symmetric nature of the response – e.g., between 0 and ð in Hecht's figures).

Further, with a plurality of etalons, when used monochromatically, it would not be possible to make a one-shot measurement with Narendran's device, since the detected signal is a complicated product of each of the etalons that the detected light has passed through.

Consequently one would not look to Narendran and Kersey for teaching a device to enable one-shot measurement over a large range of strains.

Narendran teaches a device that is suitable for uses that are not only dynamic, but in which all of the sensors are being strained in a uniform manner. This is illustrated by the test rig of Fig. 7 in which two sensors are both being progressively strained as the beam 40 is deformed, but they are strained by different amounts. This is supported by Figs. 8-10 and Figs. 13-15. In the case that the strains were non-uniform the "spectrum amplitude" in Fig. 9 would not comprise peaks at a constant frequency (frequency of cyclical reflection characteristic as they are strained). (Consider the extreme example that if one etalon were at constant strain – it would produce no peak in Fig. 9.)

In summary, Narendran discloses the use of etalons, whereas Kersey discloses the use of Bragg gratings. It would not have been obvious to the skilled person to attempt to use a feature of etalons in Bragg gratings, because the skilled person would know that etalons and Bragg gratings are not equivalent to each other.

Secondly, when Narendran discloses (in col. 4, lines 43-51) using etalon cavities having different reflectivities of their partially reflecting surfaces, he is not disclosing the equivalent of different "bulk" reflectivities in the context of Bragg gratings. Instead, by varying the reflectivities of the partially reflecting surfaces of etalons, what Narendran is disclosing is varying the finesse of the etalons, which is an entirely different matter.

Consequently, the skilled person would not make the combination (for sound technical reasons), and even if the skilled person had made the combination, he would not have thereby arrived at the presently claimed invention.

The excess claims fee of $276.00 is enclosed.

Petition is hereby made for a three-month extension of the period to respond to the outstanding Official Action to April 16, 2004. A check in the amount of $950.00, as the Petition fee, is enclosed herewith. If there are any additional charges, or any overpayment, in connection with the filing of the amendment, the Commissioner is hereby authorized to charge any such deficiency, or credit any such overpayment, to Deposit Account No. 11-1145.

Wherefore, a favorable action is earnestly solicited.

Respectfully submitted,

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The reflected flux density at P is then $I_r = E_r E_r^*/2$, is,

$$I_r = \frac{E_0^2 r^2 (1 - e^{-i\delta})(1 - e^{+i\delta})}{2(1 - r^2 e^{-i\delta})(1 - r^2 e^{+i\delta})},$$

which can be transformed into

$$I_r = I_i \frac{2r^2(1 - \cos\delta)}{(1 + r^4) - 2r^2 \cos\delta}.$$

The symbol $I_i = E_0^2/2$ represents the incident flux density, since, of course, E_0 was the amplitude of the incident wave. Similarly, the amplitudes of the transmitted waves given by

$$E_{1t} = E_0 t t' e^{i\omega t}$$
$$E_{2t} = E_0 t t' r'^2 e^{i(\omega t - \delta)}$$
$$E_{3t} = E_0 t t' r'^4 e^{i(\omega t - 2\delta)}$$
$$\vdots$$
$$E_{Nt} = E_0 t t' r'^{2(N-1)} e^{i[\omega t - (N-1)\delta]}$$

can be added to yield

$$E_t = E_0 e^{i\omega t}\left[\frac{tt'}{1 - r^2 e^{-i\delta}}\right]. \tag{9.53}$$

Multiplying this by its complex conjugate, we obtain (Problem 9.35) the irradiance of the transmitted beam

$$I_t = \frac{I_i (tt')^2}{(1 + r^4) - 2r^2 \cos\delta}. \tag{9.54}$$

Using the trigonometric identity $\cos\delta = 1 - 2\sin^2(\delta/2)$, Eqs. (9.52) and (9.54) become

$$I_r = I_i \frac{[2r/(1 - r^2)]^2 \sin^2(\delta/2)}{1 + [2r/(1 - r^2)]^2 \sin^2(\delta/2)} \tag{9.55}$$

and

$$I_t = I_i \frac{1}{1 + [2r/(1 - r^2)]^2 \sin^2(\delta/2)}, \tag{9.56}$$

where energy is not absorbed, that is, $tt' + r^2 = 1$. If indeed none of the incident energy is absorbed, the flux density of the incoming wave should exactly equal the sum of the flux density reflected off the film and the total transmitted flux density emerging from the film. It follows from Eqs. (9.55) and (9.56) that this is the case, namely,

$$I_i = I_r + I_t. \tag{9.57}$$

This will not be true, however, if the dielectric film is replaced with a thin layer of semitransparent metal. Surface currents induced in the metal will dissipate a portion of the incident electromagnetic energy (see Section ...).

Consider the transmitted waves as described by Eq. (9.54). A maximum will exist when the denominator is as small as possible, that is, when $\cos\delta = 1$, in which case $\delta = 2\pi m$ and

$$(I_t)_{max} = I_i.$$

Under these conditions Eq. (9.52) indicates that

$$(I_r)_{min} = 0,$$

as we would expect from Eq. (9.57). Again, from Eq. (9.54) it is clear that a minimum transmitted flux density will exist when the denominator is a maximum, that is, when $\cos\delta = -1$. In that case $\delta = (2m + 1)\pi$ and

$$(I_t)_{min} = I_i \frac{(1 - r^2)^2}{(1 + r^2)^2}. \tag{9.58}$$

The corresponding maximum in the reflected flux density is

$$(I_r)_{max} = I_i \frac{4r^2}{(1 + r^2)^2}. \tag{9.59}$$

Notice that the constant-inclination fringe pattern has its maxima when $\delta = (2m + 1)\pi$ or

$$\frac{4\pi n_f}{\lambda_0} d \cos\theta_t = (2m + 1)\pi,$$

which is the same as the result we arrived at previously, in Eq. (9.36), by using only the first two reflected waves. Note, too, that Eq. (9.59) verifies that Eq. (9.50) was indeed a maximum.

The form of Eqs. (9.55) and (9.56) suggests that we introduce a new quantity, the *coefficient of finesse* F, such that

$$F \equiv \left(\frac{2r}{1 - r^2}\right)^2, \tag{9.60}$$

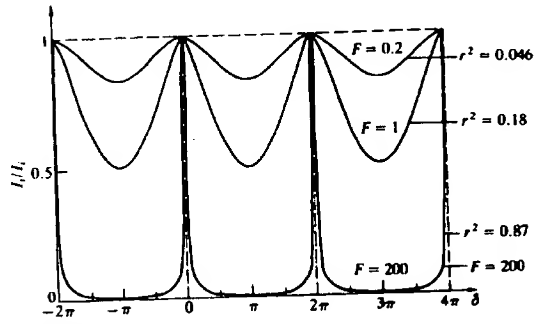

Figure 9.45 Airy function.

whereupon these equations can be written as

$$\frac{I_r}{I_i} = \frac{F \sin^2(\delta/2)}{1 + F \sin^2(\delta/2)} \tag{9.61}$$

and

$$\frac{I_t}{I_i} = \frac{1}{1 + F \sin^2(\delta/2)}. \tag{9.62}$$

The term $[1 + F \sin^2(\delta/2)]^{-1} \equiv \mathscr{A}(\theta)$ is known as the **Airy function.** It represents the transmitted flux density distribution and is plotted in Fig. 9.45. The complementary function $[1 - \mathscr{A}(\theta)]$, that is, Eq. (9.61), is plotted as well, in Fig. 9.46. When $\delta/2 = m\pi$ the Airy function is equal to unity for all values of F and therefore r. When r approaches 1, the transmitted flux density is very small, except within the sharp spikes centered about

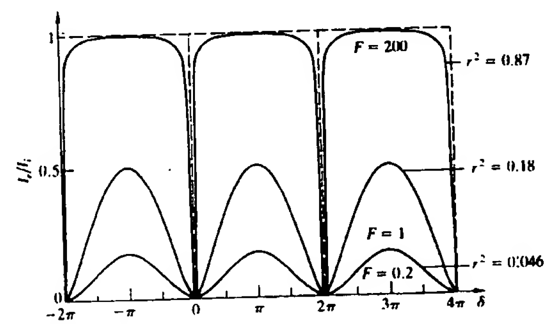

Figure 9.46 One minus the Airy function.